

Chapter 6: Minimizing Debris Generation

I. Current Activities and Research

A. Design Philosophy

Although current hardware and ongoing activities have occasionally been modified for debris prevention, the design of many future systems now includes debris-prevention objectives from the start. There are two good examples of the practical application of this philosophy. These are the studies associated with the disposal of used or waste materials from the Space Station, and the end-of-life deorbit design studies associated with the large mobile communication satellite constellation. The objectives behind these studies are not only to prevent the creation of orbital debris, but also to protect the Station itself and to avoid contamination of the surrounding environment, thus inhibiting the scientific work on the Station.

B. Operational Procedures

Some operational procedures have already been adopted by various agencies to minimize debris generation. The first area in which debris-mitigation procedures have been incorporated is in mission operations, both for launch vehicles and for payloads. The previously mentioned Delta upper stage modifications are a good example of this. The rate of debris fragment accumulation from U.S. sources has fallen to near zero as a consequence of that action alone. The disposal of spent rocket stages during flight has also been examined and in some cases altered for debris considerations. Launch planning is also affected by projections of the Collision Avoidance on Launch Program which warns of potential collisions or near misses for manned or man-capable vehicles before they are launched. Some launches have been momentarily delayed during their countdowns to avoid flying in close proximity to orbiting objects. However, it should be noted that sensor limitations affect the accuracy of any predictions. In addition, the Computation of Miss Between Orbits Program projects proximity of payloads to debris objects soon after launch, and has been used on launches of manned missions. Since 1986 the Shuttle has maneuvered three times for collision avoidance.

Procedures affecting payloads include the use of the disposal orbit for satellites at the end of their

functional lives. DOD, NOAA, INTELSAT, ESA, National Space Development Agency of Japan (NASDA), NASA and others have boosted aging satellites to altitudes above geosynchronous orbits, attempting to reduce the probabilities of debris-producing collisions in GEO and freeing up valuable GEO orbital slots.

The second area in which debris-minimizing procedures have been adopted is the in-space testing associated with military programs. This testing is principally accomplished by means of mathematical modeling, but validation tests must be performed in space prior to development decisions. Experience from DOD space experiments involving the creation of orbital debris has proved that we can minimize the accumulation of debris by careful planning. The Delta 180 Space Defense Initiative test was planned in such a way that nearly all of the debris generated by these tests reentered within 6 months. This is because the test was conducted at low altitude to enhance orbital decay of the debris.

Predictions of the amount of debris and its orbital characteristics were made to assess range safety, debris orbit lifetimes, and potential interference with other space programs. The post-mission debris cloud was observed to verify predictions and to improve the breakup models. Such debris-minimizing test operations are now standard procedure, consistent with test requirements.

II. Options for Improvement and Future Research

Options are available to control, limit, or reduce the growth of orbital debris. However, none of them can significantly modify the current debris environment; they can only influence the future environment. The three generic options of debris control are:

- (1) Mitigating Options, such as booster and payload design, preventing spontaneous explosions of rocket bodies and spacecraft, and particle-free propellant research.
- (2) Disposal or elimination of orbital debris objects.
- (3) Active removal or cleaning activities.

A. Mitigation

Launch vehicles and spacecraft can be designed so that they are litter-free; i.e., they dispose of separation devices, payload shrouds, and other expendable hardware (other than upper stage rocket bodies) at a low enough altitude and velocity that they do not become orbital. This is more difficult to do when two spacecraft share a common launch vehicle. In addition, stage-to-stage separation devices and spacecraft protective devices such as lens covers and other potential debris can be kept captive to the stage or spacecraft with lanyards or other provisions to minimize debris. This is being done in some cases as new build or new designs allow. These practices should be continued and expanded when possible.

The task of litter-free operations could combine design and operational practices to achieve the goal of limiting further orbital debris created by any space operations. As a result of these efforts, the growth rate of orbital debris will decline, although the overall debris population will still increase.

When stages and spacecraft do not have the capability to deorbit, they need to be made as inert as feasible. Expelling all propellants and pressurants and assuring that batteries are protected from spontaneous explosion require modifications in either design or operational practices for both stages and spacecraft. For systems that have multiburn (restart) capability, there are generally few, if any, design modifications required. For systems that do not have multiburn capability, design modifications to expel propellants are more extensive. Research could be conducted to develop particle-free solid propellants. If successful, this technology research effort could eliminate the aluminum oxide (Al_2O_3) particulates produced by current solid rocket motor propellants. Such a program already exists for tactical missile propellant, but there is no work currently being performed for space applications.

B. Disposal

Disposal or deorbiting of spent upper stages or spacecraft is a more aggressive and effective strategy than merely inerting spent stages and spacecraft, since it removes from the environment significant mass that could become future debris.

For new spacecraft and launch systems, there are a large number of tradeoffs as to the physical and functional interface between the stage and spacecraft which can minimize the adverse effect of implementing a disposal requirement. Studies are required to assess the cost effectiveness of these tradeoffs, given a particular system and mission.

For near-term concerns, the highest priority for disposal must be given to high-use altitudes. However, disposal of debris at these altitudes is most costly and difficult. Two types of approaches might be explored: mission design and system configuration and operations. Each needs to be applied to both LEO and GEO systems. Studies are required to assess the cost effectiveness of these options given a particular system and mission.

Mission Design. Some debris can be disposed of by careful mission design, but this may sometimes result in a significant performance penalty to both spacecraft and launch systems.

For some missions, the performance of the launch vehicle has a sufficient margin that the stage has propellant available to do a deorbit burn. The stage needs to be modified to provide the mission life and guidance and control capabilities needed to do a controlled deorbit.

When the mission requires delivery of a spacecraft which itself has a maneuver capability, two alternatives are possible. One is to leave the upper stage attached for delivery of the spacecraft to orbit to maximize its maneuver capability. The second is to separate the spacecraft at suborbital velocity so that the stage decays naturally and the spacecraft uses its onboard propulsion to establish its orbit. From a cost-penalty perspective, the first alternative results in a greater mass in orbit, a potential debris hazard, while the second alternative increases the complexity of the spacecraft. Assessing which alternative is more appropriate requires further study.

An alternative to entry and ocean disposal is relocation to a “trash” orbit. In LEO, this is not an advantageous strategy because it generally requires a two-burn maneuver that is more costly in terms of fuel than the single burn that is required for entry. During the 1980’s and early 1990’s, the Soviet Union used a trash orbit in LEO to dispose of 31 of their nuclear power sources.

Another alternative to a controlled direct entry is a maneuver which lowers the perigee such that the inertial orbital lifetime is constrained to a period such as 25 years. Such a maneuver removes the object from the region of high hazard quickly and removes the mass and cross section from orbit in a small fraction of the orbital lifetime without such a maneuver. This is significantly less costly than a targeted entry. It makes the eventual reentry happen earlier, but raises questions regarding liability issues.

For GEO missions, the pertinent considerations for disposal are the launch date, launch azimuth, and the perigee of the transfer stage. For multiburn systems, positive ocean disposal can be achieved

with an apogee burn of a few meters/second if the stage has sufficient battery lifetime and contains an attitude reference and control system.

In addition, there is a set of launch times to GEO which so align the orbit of the transfer stage that natural forces, e.g., Sun, Moon, Earth properties etc., act to lower or raise the perigee of the stage. Consideration of the effect of these forces can minimize the cost of active control of liquid propellant stages and is a low-cost technique for the disposal of solid rocket motor stages. The only alternative strategy for the disposal of solid rocket motors is to orient the thrust vector of the rocket in a direction so that the perigee of the transfer orbit resulting from the burn is at a low enough altitude to cause the stage eventually to reenter (sometimes referred to as an off-axis burn). This strategy results in about a 15% performance penalty for the stage.

Use of disposal orbits is a technically feasible strategy for clearing the geostationary orbit region, but is not the only available strategy. The cost effectiveness of a disposal orbit strategy compared with other strategies has not been examined. If raising the orbit is to be the technique of choice, then it requires planning and reserving the necessary propellant resources to effect the maneuver. Preliminary studies indicate that the orbit needs to be raised on the order of 300 km to serve the intended purpose, not the 40 to 70 km that has been used by some operators. The performance cost to reboost is 3.64 m/s for each 100 km or 1.69 kg of propellant for each 1000 kg of spacecraft mass. To reboost 300 km is comparable to 3 months stationkeeping.

System Configuration and Operations Studies. Mission design appears to be the least-cost option for disposal. However, systems not designed with a disposal requirement have other alternatives available, such as design modifications to current systems or design attributes for new systems.

For LEO stages or spacecraft, it may be feasible to maneuver to lower the perigee and employ some device to significantly increase drag. In geosynchronous transfer stages, the design and operation timeline could be modified so that the separation and avoidance maneuver could provide the velocity increment to cause the stage to enter.

In the mission design studies noted above, preliminary surveys of the concepts have been conducted. However, systematic studies and cost-effectiveness assessments are also required.

C. Removal

Removal is the elimination of space objects by another system. The following discussion pertains only to LEO because at present there is no capability nor perceived need for a removal system

at GEO. Removal options may also raise significant international legal issues. These issues are discussed in Chapter 9, Legal Issues.

Large Objects. The removal of large, inert objects requires an active maneuver vehicle with the capability to rendezvous with and grapple an inert, tumbling, and noncooperative target and the ability to properly and accurately apply the required velocity increment to move the object to a desired orbit. These capabilities have been demonstrated by the Space Shuttle, but no unmanned system has these capabilities for higher altitudes and inclinations. OSTP released a Commerce Business Daily (CBD) Announcement during the development of this report. One reply to the CBD Announcement proposed the study of just such a capability.

The design, development, and operation of a maneuverable stage to remove other stages and spacecraft requires a high degree of automation in rendezvous, grapple, and entry burn management if operations costs are to be kept reasonable. The long- and short-range systems to acquire, assess the orientation, grapple, secure, determine the center of mass, and plan the duration and timing of the entry burn all require development and demonstration of both capability and cost effectiveness. The component technologies require study and analysis, followed by breadboard and prototype development.

Small Objects. The multiplicity of small objects makes it impossible to actively acquire and enter each object individually. There are two classes of schemes that have been proposed for the removal of such debris. One is the use of active or passive devices to intercept particles with a medium, such as a large foam balloon, which absorbs kinetic energy from the particles. This causes the objects' perigee to fall to regions where aerodynamic drag induces entry. The other is an active device which illuminates the particle with a beam of directed energy, causing the particle either to lose velocity or to be dissipated into fragments that are no longer of significant mass.

Since the intercept balloon does not discriminate between debris and functioning spacecraft, it could inflict damage on usable assets. Avoidance of such damage might require active maneuvers by the intercept balloon. The advantages of a simple system could be lost if the system's operation becomes too complicated.

The active directed energy system requires elements that do not yet exist. This system requires high energy output, high precision pointing and instruments for debris object detection and beam aiming so the intercept can be accomplished

without accidentally harming other operational spacecraft.

The development of the detection and aiming instruments has a great deal in common with similar detectors required for the environmental monitoring task and the collision avoidance task. In summary there are many proven debris mitigation

options available to builders of future spacecraft. The selection of which of these options to choose is driven mainly by the requirements of a given system. The removal of debris from orbit is a far different issue. While many removal schemes have been proposed, none has yet to reach the stage where it can be considered feasible or practical.



This image of the Small Expendable Deployer System (SEDS) tether shows the 7-kilometer remains of a 20-kilometer tether. The large end mass is the Delta second stage from which the tether was deployed and the smaller end object the frayed end where the tether was severed by a piece of debris or a meteoroid after four days of flight. The image was generated by a Super-RADOT (Recording Automatic Digital Optical Tracker) 1.5-meter telescope at Kwajalein Atoll on March 19, 1994. While only 5 mm wide the tether is visible to the naked eye and the telescope because of its extended length. At its full length of 20 km, its total area is 20 square meters, or roughly the same size as most spacecraft. It illustrates how a large area and a flimsy structure are vulnerable to even the smallest debris.